DEVELOPMENT OF DYNAMIC PROGRAMMING ALGORITHM FOR MAINTENANCE SCHEDULING PROBLEM

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SUPERVISOR'S DECLARATION

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Master of Science.

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I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

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ABSTRAK

Penyelenggaraan merupakan salah satu kaedah yang boleh digunakan untuk memastikan mesin dan peralatan dapat beroperasi dalam keadaan yang baik. Jadual penyelenggaraan merupakan salah satu kaedah penyelenggaraan dan perancangan penyelenggaraan yang boleh digunakan untuk mengkoordinasi kerja-kerja penyelenggaraan supaya proses penyelenggaraan dapat dilaksanakan dengan baik dan selesai tepat pada waktu yang sepatutnya. Apa, bila, di mana dan bagaimana operasi tertentu akan dijalankan akan ditetapkan bagi memastikan pelaksanaan berjalan dengan lancar. Walau bagaimanapun, keadaan yang tidak menentu yang berlaku semasa penyelenggaraan akan menjejaskan jadual asal dan menyebabkan kelewatan atau penundaan tugas yang telah dijadualkan. Oleh itu, kajian ini adalah untuk membangunkan algoritma pengaturcaraan yang dinamik bagi masalah penjadualan penyelenggaraan yang boleh mengambil kira keadaan yang tidak menentu ketika penyelenggaraan dan menghasilkan jadual penyelenggaraan optimum yang lain. Penyelidikan mengenai masalah ini bermula dengan mengkaji semula penyelidikan sebelumnya untuk mencari jurang dan mencari penyelesaian bagi jurang tersebut. Kemudian, data pasukan penyelenggaraan dari salah satu syarikat penyedia utiliti di Malaysia telah dikumpul untuk digunakan dalam pembangunan algoritma pengaturcaraan dinamik tersebut. Model pengaturcaraan dinamik yang dibangunkan untuk penyelidikan ini refleks kepada aliran aktiviti penyelenggaraan syarikat dan mengimplimentasikan model oleh Lieberman dan Hillier (2010). Kemudian, dari model yang dibangunkan, formulasi telah dirumuskan. Model ini kemudiannya disimulasikan dengan menggunakan data yang dikumpulkan untuk mengesahkan sama ada model ini beroperasi seperti yang dinginkan dan boleh digunakan untuk mencapai matlamat penyelidikan ini. Setelah model itu dibangunkan, pengiraan untuk menentukan jadual penyelenggaraan optimum telah dilakukan dengan menggunakan formulasi pengaturcaraan dinamik yang digubal. Pengiraan dilakukan dengan menggunakan perisian Microsoft Office Excel dan jadual untuk setiap pasukan penyelenggaraan yang diperoleh dipaparkan dalam jadual. Model ini kemudiannya diperakui dapat menghasilkan penjadualan semula walaupun berlaku keadaan yang tidak menentu ketika proses penyelenggaraan. Kombinasi jadual yang banyak dapat dihasilkan dari model pengaturcaraan dinamik dan fleksibiliti model dapat ditingkatkan dengan meningkatkan varieti pilihan untuk memilih jadual mengikut keutamaan penyelidikan yang meminimumkan jumlah masa untuk menyelesaikan aktiviti penyelenggaraan. Model ini juga mampu untuk menjadualkan semula dengan menggantikan pasukan yang tidak tersedia dengan pasukan lain untuk mengelakkan kelewatan menggunakan algoritma pengaturcaraan dinamik yang dihasilkan. Jadual penyelenggaraan optimum kemudiannya dijana dengan membandingkan semua jumlah masa yang telah dikira dan memilih jumlah masa paling minimum. Pengoptimuman jadual penyelenggaraan ini dapat menjimatkan masa dan mengelakkan kelewatan untuk aktiviti penyelenggaraan pasukan penyelenggaraan yang serentak akan mengurangkan kos untuk membayar jam kerja tambahan pasukan yang terlibat.

ABSTRACT

Maintenance is one of the important methods that can be used to ensure machines and equipment can operate at the best condition. Maintenance schedule is one of the maintenance management and planning methods that can be used to organize and coordinate timely maintenance work. What, when, where and how the certain operation will be done will be stated to make sure that the planned activity is going smoothly without any delays. However, the uncertainty that happened during maintenance or inspections will affect the original schedule and lead to delays or suspension of the task that had been scheduled. Thus, the original schedule proposed will be useless and rescheduling needs to be done. The objectives of this research are to develop a dynamic programming algorithm for the maintenance scheduling problem that can deal with the uncertainty and to determine the optimum maintenance schedule that will change according to the uncertainty that happened. This research starts with reviewing the previous researches to find the gap in knowledge and find the possible solutions of the gap found. Then, the data of the maintenance team from one of the utilities provider company in Malaysia was collected to be implemented in the development of a dynamic programming algorithm. The dynamic programming model developed for this research reflected the flow of the maintenance activity of the company and implemented the model by Lieberman and Hillier (2010). Then, from the model developed, a formulation was created based on the problem of the maintenance schedule proposed. This model was then simulated using the data collected to verify whether the model was operating effectively and can be used to achieve the objective of this research. Once the model was developed, the calculations to determine the optimum maintenance schedule were done using the dynamic programming formulation created for this maintenance scheduling problem. The calculation was done using the Microsoft Office Excel software and the schedules for each maintenance team obtained were displayed in the result section. The model was then tested by the assumptions to verify that the model can reschedule after dealing with the uncertainty. The dynamic programming model developed was capable to produce the possible combinations and is flexible enough to deal with the uncertainties during the maintenance activity by increasing the choice of scheduling varieties according to the preference of the research which was to minimize the total time of the maintenance schedule. Using the dynamic programming algorithm developed, the model was also able to recalculate alternative schedules by replacing unavailable teams with other teams to avoid delays. The optimum maintenance schedule was then generated by comparing all of the total time of all the possible outcomes and selecting the most minimum total time which simultaneously will reduce the cost to pay for the extra working hours of the teams involved.

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LIST OF ABBREVIATIONS

MTBF	Meantime before failure
MTTR	Meantime to repair
AGAN	As good as new
ABAO	As bad as old
ROCOF	Rate of occurrence of failure
CLSP	Capacitate lot-sizing problem

LIST OF APPENDICES

REFERENCES

Aghezzaf, E. H., Jamali, M. A., & Ait-Kadi, D. (2007). An integrated production and preventive maintenance planning model. *European Journal of Operational Research*, *181*(2), 679–685. https://doi.org/10.1016/j.ejor.2006.06.032

Al-hammad, A., Assaf, S., & Al-shihah, M. (2009). A literature review and future perspectives on maintenance optimization. *Journal of Quality in Maintenance Engineering*, *3*(1997), 29–39. https://doi.org/10.1108/13552510810877674

Almomani, M., Abdelhadi, A., Seifoddini, H., & Xiaohang, Y. (2012). Preventive maintenance planning using group technology: A case study at Arab Potash Company, Jordan. *Journal of Quality in Maintenance Engineering*, *18*(4), 472–480. https://doi.org/10.1108/13552511211281624

Alpan, G., Larbi, R., & Penz, B. (2011). A bounded dynamic programming approach to schedule operations in a cross docking platform. *Computers and Industrial Engineering*, *60*(3), 385–396. https://doi.org/10.1016/j.cie.2010.08.012

Astaraky, D., & Patrick, J. (2015). A simulation based approximate dynamic programming approach to multi-class, multi-resource surgical scheduling. *European Journal of Operational Research*, *245*(1), 309–319. https://doi.org/10.1016/j.ejor.2015.02.032

Azhar, N. A. C., & Mansor, M. A. (2013). Development of Plant Maintenance Management System(PMMS): A Case Study. *International Conference on Mechanical Engineering Research (ICMER2013), 1-3 July 2013*, (July), 1–3.

Baker, K. R., & Trietsch, D. (2009). *Principles of Sequencing and Scheduling*. (Lilit Mazmanyan, Ed.), *Principles of Sequencing and Scheduling*. John Wiley & Sons, Inc. https://doi.org/10.1002/9780470451793

Balaji, G., Balamurugan, R., & Lakshminarasimman, L. (2016). Mathematical approach assisted differential evolution for generator maintenance scheduling. *International Journal of Electrical Power and Energy Systems*, *82*, 508–518. https://doi.org/10.1016/j.ijepes.2016.04.033

Bellman, R. (1957). Functional equations in the theory of dynamic programming--VII. A partial differential equation for the Fredholm resolvent. *Proceedings of the American Mathematical Soviety*, *8*(3), 435–440.

Besnard, F., Patriksson, M., Strömberg, A., Fischer, K., & Bertling, L. (2011). A stochastic model for opportunistic maintenance planning of offshore wind farms. *2011 IEEE Trondheim PowerTech*, 1–8. https://doi.org/10.1109/PTC.2011.6019376

Bian, Z., Shao, Q., & Jin, Z. (2015). Optimization on the container loading sequence based on hybrid dynamic programming. *Transport*, *4142*(February), 1–10. https://doi.org/10.3846/16484142.2014.994563

Budai, G., Dekker, R., & Nicolai, R. P. (2008). Maintenance and Production: A Review of Planning Models. *Springer Series in Reliability Engineering*, *8*(2001), 321–344. https://doi.org/10.1007/978-1-84800-011-7_13

Chen, W.-J., & Liao, C.-J. (2005). Scheduling with different maintenance policies in a textile company. *Journal of Quality in Maintenance Engineering*, *11*(1), 43–52. https://doi.org/10.1108/13552510510589361

Cho, J. H., Kim, H. S., & Choi, H. R. (2012). An intermodal transport network planning algorithm using dynamic programming-A case study: From Busan to Rotterdam in intermodal freight routing. *Applied Intelligence*, *36*(3), 529–541. https://doi.org/10.1007/s10489-010-0223-6

Elshafei, M., Khan, M., & Duffuaa, S. O. (2016). Repeat inspection planning using dynamic programming.PDF. *International Journal of Production Research*, *44*(February), 257–270. https://doi.org/10.1080/13528160500245749

Erdelyi, A., & Topaloglu, H. (2010). Approximate dynamic programming for dynamic capacity allocation with multiple priority levels. *IIE Transactions*, *43*(2), 129–142. https://doi.org/10.1080/0740817X.2010.504690

Fitouhi, M. C., & Nourelfath, M. (2012). Integrating noncyclical preventive maintenance scheduling and production planning for a single machine. *International Journal of Production Economics*, *136*(2), 344–351. https://doi.org/10.1016/j.ijpe.2011.12.021

Froger, A., Gendreau, M., Mendoza, J. E., Pinson, É., & Rousseau, L.-M. (2015). Maintenance scheduling in the electricity industry: A literature review. *European Journal of Operational Research*, *251*(3), 695–706. https://doi.org/10.1016/j.ejor.2015.08.045

Garg, A. A., & Deshmukh, S. G. (2006). *Maintenance management: literature review and directions*. *Journal of Quality in Maintenance Engineering* (Vol. 12). https://doi.org/http://dx.doi.org/10.1108/13552510610685075

Gharbi, A., & Kenne, J. P. (2004). Stohastic optimal production control problem with corrective maintenance. *Computers & Industrial Engineering*, *46*, 865–875. https://doi.org/10.1016/j.cie.2004.05.024

Grall, A., Berenguer, C., & Dieulle, L. (2002). A condition-based maintenance policy for stochastically deteriorating systems. *Reliability Engineering and System Safety*, *76*(2), 167–180. https://doi.org/10.1016/S0951-8320(01)00148-X

Hao, C., & Yue, Y. (2016). Optimization on Combination of Transport Routes and Modes on Dynamic Programming for a Container Multimodal Transport System. *Procedia Engineering*, *137*, 382–390. https://doi.org/10.1016/j.proeng.2016.01.272

Hartman, J. C., Büyüktahtakin, İ. E., & Smith, J. C. (2010). Dynamic-programming-based inequalities for the capacitated lot-sizing problem. *IIE Transactions*, *42*(12), 915–930. https://doi.org/10.1080/0740817X.2010.504683

Hillston, J. (2017). Model Validation and Verification. Retrieved from www.inf.edu.ac.uk

Kocatepe, O. (2014). An application framework for scheduling optimization problems. In *IEEE 8th International Conference on Application of Information and Communication Technologies (AICT)* (pp. 1–4). https://doi.org/10.1109/ICAICT.2014.7035950

Laohanan, S., & Banjerdpongchai, D. (2019). Dynamic programming approach to optimal maintenance scheduling of substation equipment considering life cycle cost and reliability. *ECTI-CON 2018 - 15th International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology*, 388–391. https://doi.org/10.1109/ECTICon.2018.8619884

Li, H., & Womer, N. K. (2015). Solving stochastic resource-constrained project scheduling problems by closed-loop approximate dynamic programming. *European Journal of Operational Research*, *000*, 1–14. https://doi.org/10.1016/j.ejor.2015.04.015

Lieberman, G. J., & Hillier, F. S. (2010). *Introduction to OPERATIONS RESEARCH Ninth Edition* (Ninth Edit). Mc Graw Hill.

Liu, D., Xu, Y., Wei, Q., & Liu, X. (2018). Residential energy scheduling for variable weather solar energy based on adaptive dynamic programming. *IEEE/CAA Journal of Automatica Sinica*, *5*(1), 36–46. https://doi.org/10.1109/JAS.2017.7510739

Liu, Q., Dong, M., Lv, W., & Ye, C. (2019). Manufacturing system maintenance based on dynamic programming model with prognostics information. *Journal of Intelligent Manufacturing*, *30*(3), 1155–1173. https://doi.org/10.1007/s10845-017-1314-6

Mansor, M. A., Ohsato, A., & Sulaiman, S. (2012). Knowledge Management for Maintenance Activities in the Manufacturing Sector. *International Journal of Automotive and Mechanical Engineering (IJAME)*, *5*(June), 612–621.

Marseguerra, M., Zio, E., & Podofillini, L. (2002). Condition-based maintenance optimization by means of genetic algorithms and Monte Carlo simulation. *Reliability Engineering and System Safety*, *77*(2), 151–166. https://doi.org/10.1016/S0951-8320(02)00043-1

Matsuoka, S., & Muraki, M. (2007). Short-term maintenance scheduling for utility systems. *Journal of Quality in Maintenance Engineering*, *13*(3), 228–240. https://doi.org/10.1108/13552510710780267

Moghaddam, K. S., & Usher, J. S. (2011a). Preventive maintenance and replacement scheduling for repairable and maintainable systems using dynamic programming. *Computers and Industrial Engineering*, *60*(4), 654–665. https://doi.org/10.1016/j.cie.2010.12.021

Moghaddam, K. S., & Usher, J. S. (2011b). Sensitivity analysis and comparison of algorithms in preventive maintenance and replacement scheduling optimization models. *Computers & Industrial Engineering*, *61*(1), 64–75. https://doi.org/10.1016/j.cie.2011.02.012

Nakajima, S., & Shirase, K. (1992). *New TPM development program for assemby process (in Japanese).* JIPM Solution, Tokyo, Japan.

Nawara, G., & Hassanein, E. (2013). Solving the Job-Shop Scheduling Problem by Arena Simulation Software. *International Journal of …*, *2*(2), 161–166. Retrieved from http://www.researchgate.net/publication/236631006_Solving_the_Job-Shop_Scheduling_Problem_by_Arena_Simulation_Software/file/60b7d523d5571c3b3e.pdf

Pablo, D. a. L. De. (2009). On scheduling models: An overview. *2009 International Conference on Computers & Industrial Engineering*, (1972), 153–158. https://doi.org/10.1109/ICCIE.2009.5223704

Pan, Z., Tang, J., & Liu, O. (2009). Capacitated dynamic lot sizing problems in closed-loop supply chain. *European Journal of Operational Research*, *198*(3), 810–821. https://doi.org/10.1016/j.ejor.2008.10.018

Parr, S., & Kaisar, E. (2011). Critical Intersection Signal Optimization During Urban Evacuation Utilizing Dynamic Programming. *Journal of Transportation Safety & Security*, *3*(1), 59–76. https://doi.org/10.1080/19439962.2011.532297

Pinson, E. (2016). Solving a wind turbine maintenance scheduling problem. *Interuniversity Research Centre on Enterprice Networks, Logistics and Transportation*, (August).

Rebai, M., Kacem, I., & Adjallah, K. H. (2013). Scheduling jobs and maintenance activities on parallel machines. *Operational Research*, *13*(3), 363–383. https://doi.org/10.1007/s12351-012-0130-1

Reklaitis, G. V. (2000). Overview of Planning and Scheduling Technologies. *Latin American Aplied Research*, *293*(30), 285–293.

Sargent, R. G. (2010). Verification and validation of simulation models. In *Proceedings of the 2010 Winter Simulation Conference* (pp. 166, 183). IEEE. https://doi.org/10.1109/WSC.2010.5679166

Schmid, V. (2012). Solving the dynamic ambulance relocation and dispatching problem using approximate dynamic programming. *European Journal of Operational Research*, *219*(3), 611–621. https://doi.org/10.1016/j.ejor.2011.10.043

Sukhov, P., Batsyn, M., & Terentev, P. (2014). A dynamic programming heuristic for optimizing slot sizes in a warehouse. *Procedia Computer Science*, *31*, 773–777. https://doi.org/10.1016/j.procs.2014.05.327

Sundström, O., Guzzella, L., & Soltic, P. (2008). Optimal Hybridization in Two Parallel Hybrid Electric Vehicles using Dynamic Programming. *Proceedings of the 17th IFAC World Congress*, *1*, 4642–4647. https://doi.org/10.3182/20080706-5-KR-1001.00781

Taylor, P., Danilovic, D., Maricic, V. K., & Ristovic, I. (2011). Determination of Optimal Parameters of Distributive Gas Pipeline by Dynamic Programming Method. *Petroleum Science and Technology*, *6466*(April 2013), 37–41. https://doi.org/10.1080/10916460903468443

Van Den Bergh, J., Beliën, J., De Bruecker, P., Demeulemeester, E., & De Boeck, L. (2013). Personnel scheduling: A literature review. *European Journal of Operational Research*, *226*(3), 367–385. https://doi.org/10.1016/j.ejor.2012.11.029

Van Horenbeek, A., Pintelon, L., & Muchiri, P. (2010). Maintenance optimization models and criteria. *International Journal of Systems Assurance Engineering and Management*, *1*(3), 189–200. https://doi.org/10.1007/s13198-011-0045-x

Walker, R. A. (1995). Introduction to the Scheduling Problem. *IEEE Design &Test of Computers*, 60–69.

Wang, G., Gong, W., DeRenzi, B., & Kastner, R. (2007). Ant colony optimizations for resource- and timing-constrained operation scheduling. *IEEE Transactions on Computer-Aided Design of Integrated Circuits and Systems*, *26*(6), 1010–1028. https://doi.org/10.1109/TCAD.2006.885829

Wirahadikusumah, R., & Abraham, D. M. (2003). Application of dynamic programming and simulation for sewer management. *Engineering, Construction and Architectural Management*, *10*(3), 193–208. https://doi.org/10.1108/09699980310478449

Xiao, Y., & Konak, A. (2016). A genetic algorithm with exact dynamic programming for the green vehicle routing & scheduling problem. *Journal of Cleaner Production*, *167*, 1450–1463. https://doi.org/10.1016/j.jclepro.2016.11.115

Yang, X., Li, X., Gao, Z., Wang, H., & Tang, T. (2013). A cooperative scheduling model for timetable optimization in subway systems. *IEEE Transactions on Intelligent Transportation Systems*, *14*(1), 438–447. https://doi.org/10.1109/TITS.2012.2219620

Yang, Y., Hu, X., Pei, H., & Peng, Z. (2016). Comparison of power-split and parallel hybrid powertrain architectures with a single electric machine: Dynamic programming approach. *Applied Energy*, *168*, 683–690. https://doi.org/10.1016/j.apenergy.2016.02.023

Ye, X., Xia, X., Zhang, L., & Zhu, B. (2015). Optimal maintenance planning for sustainable energy efficiency lighting retrofit projects by a control system approach. *Control Engineering Practice*, *37*, 1–10. https://doi.org/10.1016/j.conengprac.2014.12.014

Yu, R., Zhong, W., Xie, S., Zhang, Y., & Zhang, Y. (2016). QoS Differential Scheduling in Cognitive-Radio-Based Smart Grid Networks: An Adaptive Dynamic Programming Approach. *IEEE Transactions on Neural Networks and Learning Systems*, *27*(2), 435–443. https://doi.org/10.1109/TNNLS.2015.2411673

Yuan, Y., & Tang, L. (2017). Novel time-space network flow formulation and approximate dynamic programming approach for the crane scheduling in a coil warehouse. *European Journal of Operational Research*, *262*, 424–437. https://doi.org/10.1016/j.ejor.2017.03.007

Zhang, X., Wu, C., & Zuo, L. (2016). Minimizing fuel consumption of a gas pipeline in transient states by dynamic programming. *Journal of Natural Gas Science and Engineering*, *28*, 193–203. https://doi.org/10.1016/j.jngse.2015.11.035

Zhen, L., Wang, S., & Zhuge, D. (2017). Dynamic programming for optimal ship refueling decision. *Transportation Research Part E: Logistics and Transportation Review*, *100*(December 2015), 63–74. https://doi.org/10.1016/j.tre.2016.12.013